Chapter 9
Thermal Spray Coating Inspection and Testing

9-1. Introduction

This chapter discusses the importance of conducting and documenting various quality control and quality assurance procedures for surface preparation, thermal spraying, and sealing operations. Each procedure is critical in ensuring that a quality coating system is applied.

9-2. Reference Samples and the Thermal Spray Job Reference Standard

a. Reference samples. Reference samples of each material used on a thermal spray job should be collected, including clean, unused abrasive blast media, thermal spray wire, sealer, and paint. Samples may be used to evaluate the conformance of materials to any applicable specifications. A 1-kg (2.2-lb.) sample of blast media should be collected at the start of the job. The sample may be used to verify the cleanliness, media type, and particle size distribution of the virgin blast media. A 30-cm (12-in.) sample of each lot of thermal spray wire should be collected. The wire sample may be used to confirm that the manufactured wire conforms to the size and compositional requirements of the contract. For powdered materials, a 1-kg (2.2-lb.) sample should be collected. One-liter (1-quart) samples of all sealers and paints should be collected for compliance testing.

b. Thermal spray job reference standard. A thermal spray job reference standard (JRS) should be prepared. The JRS may be used at the initiation of a thermal spray contract to qualify the surface preparation, thermal spray application, and sealing processes. The JRS may also serve as a standard of quality in case of dispute.

(1) Preparing the JRS. The JRS should be prepared prior to the onset of production work. To prepare the JRS, a steel plate of the same alloy and thickness, measuring 60 × 60 cm (2 × 2 ft), should be solvent and abrasive-blast cleaned in accordance with the requirements of the contract. The abrasive blast equipment and media used for the JRS should be the same as those that will be used on the job. One-fourth of the JRS plate should be masked with sheet metal, and the thermal spray coating should be applied to the unmasked portion of the plate. The thermal spray coating should be applied using the same equipment and spray parameters proposed for use on the job. The gun should be operated in a manner substantially the same as will be used on the job. The approximate traverse speed and standoff distance during spraying should be measured and recorded. Once the JRS is qualified, the operating parameters should not be altered by the contractor, except as necessitated by the requirements of the job. Two-thirds of the thermal spray coated portion of the JRS should be sealed in accordance with the requirements of the contract. One-half of the sealed area should be painted in accordance with the contract if applicable. The sealer and paint should be applied using the same paint spray equipment that will be used for production. The prepared JRS should be preserved and protected in such a manner that it remains dry and free of contaminants for the duration of the contract. The preserved JRS should then be archived for future reference in the event of a dispute or premature coating failure. Figure 9-1 depicts a representative JRS.

(2) Evaluating the JRS. The surface cleanliness, blast profile shape and depth, thermal spray appearance, thickness, and adhesion, and sealer and paint thicknesses should be determined in accordance with the contract requirements and recorded. Paragraphs 9-10, 9-11, and 9-14 through 9-17 provide additional details on performing these evaluations. The JRS and the measured values may be used as a visual reference or job standard for surface preparation, thermal spray coating, sealing, and painting.

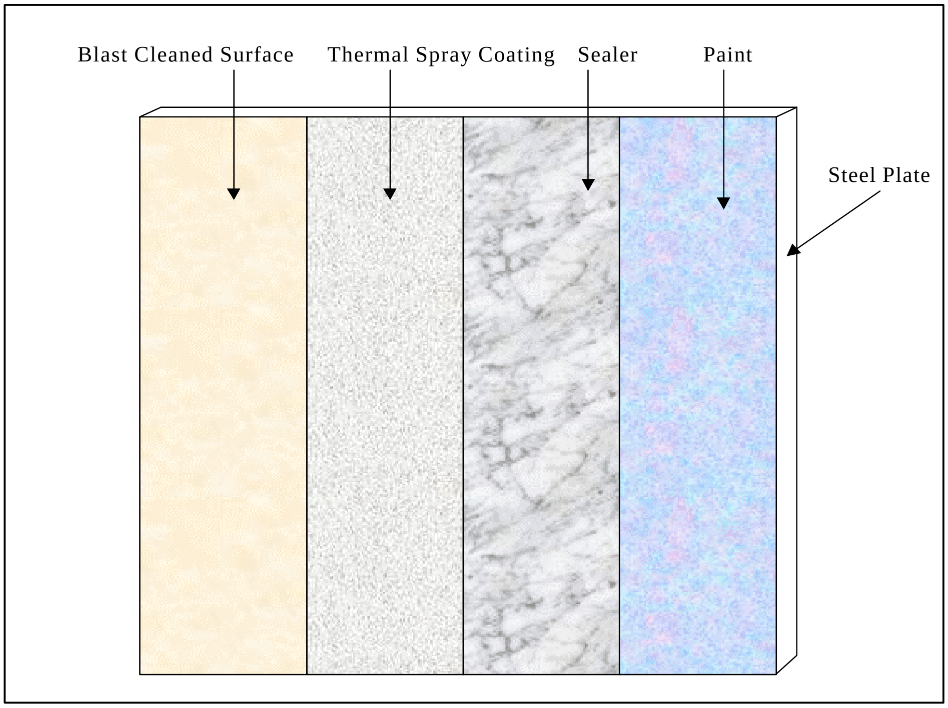

Figure 9-1. Representative job reference standard

9-3. Presurface Preparation Inspection

Prior to abrasive blasting, the substrate should be inspected for the presence of contaminants, including grease and oil, weld flux and spatter, heat-affected zones, pitting, sharp edges, and soluble salts.

(1) Grease and oil. Painted surfaces and newly fabricated steel should be visibly inspected for the presence of organic contaminants such as grease and oil as required by the project specification. A black light may be used to increase the sensitivity of the evaluation, as grease and oil deposits will fluoresce under the light. Solvent evaporation and heat tests may be used to detect thin films of oil contamination on steel surfaces.

(2) Weld flux and spatter. A visual inspection for the presence of weld flux and spatter should be performed as required by the project specification. Weld flux should be removed prior to abrasive blast cleaning using a suitable SSPC-SP 1 “Solvent Cleaning” method. Weld spatter may be removed either before or after abrasive blasting using suitable impact or grinding tools. Areas that are power-tool cleaned of weld spatter should be abrasive blast cleaned.

(3) Heat affected zones. Heat affected zones should be identified and marked prior to abrasive blasting as required by the specification. The demarcated areas should be ground using power tools prior to abrasive blast cleaning.

(4) Pitting. Deep pits or pitted areas should be identified and marked prior to abrasive blast cleaning as required by the specification. The demarcated areas should be ground using power tools prior to abrasive blast cleaning.

(5) Sharp edges. Sharp edges should be identified and marked prior to abrasive blasting as required by the specification. The demarcated edges should be prepared by grinding to a minimum radius of 3 mm (1/8 in.) prior to blast cleaning.

(6) Soluble salts. When soluble salt contamination is suspected, the contract documents should specify a method of retrieving and measuring the salt levels as well as acceptable levels of cleanliness. Salt contamination is prevalent on structures exposed in marine environments and on structures such as parking decks and bridges exposed to deicing salts. Common methods for retrieving soluble salts from the substrate include cell retrieval methods and swabbing or washing methods. Various methods are available for assessing the quantity of salts retrieved, including conductivity, commercially available colorimetric kits, and titration. The rate of salt retrieval is dependent on the retrieval method. The retrieval and quantitative methods should be agreed upon in advance. For additional information on testing for soluble salts, refer to section 9-11, "SSPC Technology Update: Field Methods for Retrieval and Analysis of Soluble Salts on Substrates," and SSPC 91-07. Soluble salt levels should be rechecked for compliance with the specification after solvent cleaning and abrasive blasting have been completed.

9-4. Measuring Ambient Conditions Prior to Blasting

An assessment of the atmospheric conditions should be made prior to the commencement of abrasive blast cleaning. The conditions of humidity, dew point, and ambient air temperature should be measured and recorded. Humidity should be determined in accordance with ASTM E337 "Test Method for Measuring Humidity with a Psychrometer (The Measurement of Wet-Bulb and Dry-Bulb Temperatures)." In general, abrasive blasting should not be performed unless the ambient requirements for thermal spray coating and sealing are met. This is because of the rapid sequencing of surface preparation and thermal spraying and the need for a clean, rust-free surface.

9-5. Assessing Compressed Air Cleanliness

The compressed air used for abrasive blasting, thermal spraying, sealing, and painting should be clean and dry. Oil or water in the blasting air supply may contaminate or corrode the surface being cleaned. Oil or water in the thermal spray, sealing, or painting air supply may result in poor coating quality or reduced adhesion. Compressed air cleanliness should be checked in accordance with ASTM D 4285 "Method for Indicating Water or Oil in Compressed Air." The air compressor should be allowed to warm up, and air should be discharged under normal operating conditions to allow accumulated moisture to be purged. An absorbent clean white cloth should be held in the stream of compressed air not more than 60 cm (24 in.) from the point of discharge for a minimum of 1 min. The air should be checked as near as possible to the point of use and always after the position of the in-line oil and water separators. The cloth should then be inspected for moisture or staining. The compressed air source should not be used if there is any oil or water contamination present.

9-6. Determining Abrasive Cleanliness

Abrasive blast media must be free of oil and salt to prevent contamination of the substrate. Recycled steel grit abrasive should comply with requirements of SSPC-AB 2 "Specification for Cleanliness of Recycled

a. Evaluating for salt in abrasives. Most abrasives used to prepare steel substrates for thermal spraying are unlikely to contain appreciable amounts of soluble salts. However, slag abrasives used for strip blasting may sometimes contain measurable quantities of salts. Slag abrasives should be evaluated in accordance with ASTM D 4940 "Test Method for Conductimetric Analysis of Water Soluble Ionic Contamination of Blasting Abrasives."

b. Testing for oil in abrasives. To test for oil in abrasives, a clear glass container should be half filled with unused abrasive, then distilled or deionized water should be added to fill the container. The resulting slurry mixture is stirred or shaken and allowed to settle. The water is then examined for the presence of an oil sheen. If a sheen is present, the media should not be used, and the source of contamination should be determined and corrected.

9-7. Measuring Blast Air Pressure

The contractor should periodically measure and record the air pressure at the blast nozzle. The measurement should be performed at least once per shift and should be performed on each blast nozzle. Measurements should be repeated whenever work conditions are altered such that the pressure may change. Pressures should be checked concurrently with the operation of all blast nozzles. The method employs a hypodermic needle attached to a pressure gauge. The needle is inserted into the blast hose at a 45-deg angle toward and as close to the nozzle as possible. The blast pressure is read directly from the gauge.

9-8. Examining the Blast Nozzle Orifice

The contractor should visually inspect the blast nozzle periodically for wear or other damage. Gauges are available that insert into the end of the nozzle and measure the orifice diameter. Nozzles with visible damage or nozzles that have increased one size should be replaced. Worn nozzles are inefficient and may not produce the desired blast profile. Damaged nozzles may be dangerous.

9-9. Evaluating Surface Profile

a. ASTM D 4417 “Test Methods for Field Measurements of Surface Profile on Blast Cleaned Steel” Method C is the recommended method for measuring the surface profile depth. Recommended surface profiles contained in this manual are based on values obtained using Method C. Methods A and B may provide different measures of the blast profile than Method C.

b. The method employs a replica tape and spring gauge micrometer to measure the surface profile. With the wax paper backing removed, the replica tape is placed face down against the substrate, and a burnishing tool is used to rub the circular cutout until a uniform gray appearance develops. The replica tape thickness (compressible foam plus plastic backing) is then measured using the spring micrometer. The profile is determined by subtracting the thickness of the plastic backing material, 50 μm (0.002 in.), from the measured value. Three readings should be taken within a 100-cm^2 (16-in^2) area, and the surface profile at that location should be reported as the mean value of the readings. The number of measurements per unit area (e.g., 3 per 45 m^2 (500 ft^2)) should be specified in the contract document. Two types of replica tape are available, coarse (20 to 50 μm (0.0008 to 0.002 in.)) and X-coarse (37.5 to 112.5 μm (.0015 to 0.0045 in.)). In most cases, the X-coarse tape will be used to measure profile. It may be possible to measure profiles as high as 150 μm (0.006 in.) using the X-coarse tape.

9-10. Inspecting Surface Cleanliness

After abrasive blasting and prior to thermal spraying the surface should be inspected for cleanliness, including blast cleanliness, soluble salts, grease and oil, and dust.

a. Blast cleanliness. The final appearance of the abrasive cleaned surface should be inspected for conformance with the requirements of SSPC-SP 5. An SP 5 surface is defined as free of all visible oil, grease, dirt, dust, mill scale, rust, paint, oxides, corrosion products, and other foreign matter. The appearance of SP 5 surfaces is dependent on the initial condition of the steel being cleaned. SSPC VIS 1 may be used to interpret the cleanliness of various blast cleaned substrates based on the initial condition of the steel and the type of abrasive used. Initial conditions depicted include: (1) Rust Grade A - steel surface completely covered with adherent mill scale with little or no rust visible, (2) Rust Grade B - steel surface covered with both mill scale and rust, (3) Rust Grade C - steel surface completely covered with rust with little or no pitting, (4) Rust Grade D - steel surface completely covered with rust with visible pitting. The inspector should determine the initial substrate condition or conditions. The final appearance of the surfaces can then be compared with the appropriate photograph. No stains should remain on the SP 5 surface. However, the appearance of the surface may also vary somewhat, depending on the type of steel, presence of roller or other fabrication marks, annealing, welds, and other differences in the original condition of the steel.

b. Soluble salts. Common methods for retrieving soluble salts from the substrate include cell retrieval methods and swabbing or washing methods. Various methods are available for assessing the quantity of salts retrieved, including conductivity, commercially available colorimetric kits, and titration. The rate of salt retrieval is dependent on the retrieval method. The retrieval and quantitative methods should be agreed upon in advance. The recommended procedure employs the Bresle cell (ISO 8502-6) to extract soluble salts from the substrate. Chloride ion concentration is readily measured in the field using titration strips available from Quantab. The test strip analyzes the collected sample and measures chloride ion concentration in parts per million. The unit area concentration of chloride ion is calculated in μ grams per centimeter. The lower detection limit for the Bresle/Quantab method is about 2 $\mu g/cm^2$. SSPC-SP 12/NACE No. 5 describe levels of soluble salt contamination. It is recommended that surfaces cleaned to an SC-2 condition be used for thermal spray coatings. An SC-2 condition is described as having less than 7 $\mu g/cm^2$ of chloride contaminants, less than 10 $\mu g/ cm^2$ of soluble ferrous ion, and less than 17$\mu g/cm^2$ of sulfate contaminants. Most USACE structures have low levels of soluble salt contamination, and, therefore, testing is not usually warranted. Structures that are likely to have soluble salt contamination, including those in marine or severe industrial atmospheres, bridge or other structures exposed to deicing salts, and seawater immersed structures, should be tested. The number of tests per unit area (e.g., 1 per 90 m^2 (1000 ft^2)) should be specified in the contract documents.

c. Grease and oil. Blasted surfaces should be visibly inspected for the presence of grease and oil. A black light (ultraviolet) may be used to increase the sensitivity of the evaluation, as grease and oil deposits will fluoresce under the light. Fluorescence cannot be detected in daylight so a hood or shield must be used to darken the viewing area. Grease or oil contamination is indicated by a yellow or green fluorescence. An absence of fluorescence indicates a clean surface. However, it should be noted that some synthetic oils do not fluoresce. Solvent evaporation and heat tests may also be used to detect thin films of oil contamination. The evaporation test uses a small amount (5 ml) of a residueless, highly volatile solvent, such as acetone, on the surface. The solvent is applied and allowed to evaporate. A visible ring of residue signals the presence of oil or grease contamination. The heat test uses a propane torch to heat the surface to 120 °C (250 °F) to perform a similar visual assessment.

d. Dust. Abrasive blasting, and overspray from painting or metallizing, can leave a deposit of dust on the cleaned substrate. The dust may interfere with adhesion of the thermal spray coating. Residual dust may be detected by applying a strip of clear tape to the substrate. The tape is removed and examined for adherent particles. Alternatively, a clean white cloth may be wrapped around a finger and wiped across the surface. The cloth and substrate are then examined for signs of dust. The preferred method of removing residual dust is by vacuuming. Alternatively, the surface may be blown down with clean, dry compressed air.

9-11. Measuring Ambient Conditions Prior to Thermal Spraying

A second assessment of the atmospheric conditions should be made before thermal spray application begins. The conditions of humidity, dew point, and ambient air temperature should be measured and recorded. Application should not be performed unless the ambient requirements for thermal spraying and sealing are met. This is because of the rapid sequencing of thermal spraying and sealing.

9-12. Bend Testing to Evaluate Equipment Setup

Each day, or every time the thermal spray equipment is to be used, the inspector should record and confirm that the operating parameters are the same as those used to prepare the JRS. The thermal spray applicator should then apply the coating to prepared test panels and conduct the bend test. The bend test is a qualitative test used to confirm that the equipment is in proper working condition. The test consists of bending coated steel panels around a cylindrical mandrel and examining the coating for cracking. If the bend test fails, corrective actions must be taken prior to the application of the thermal spray coating. The results of the bend test should be recorded and the test panels should be labeled and saved.

a. Test panels. The test panels should be a cold rolled steel measuring 7.5 × 15 × 1.25 cm (3 × 6 × 0.050 in.). The panels should be cleaned and blasted in the same fashion as will be used for the job.

b. Application of thermal spray. The thermal spray coating should be applied to five test panels using the identical spray parameters and average specified thickness that will be used on the job. The coating should be applied in a cross hatch pattern using the same number of overlapping spray passes as used to prepare the JRS. The coating thickness should be measured to confirm that it is within the specified range.

c. Conduct bend test. Test panels are bent 180 deg around a steel mandrel of a specified diameter. Thermal spray coating systems 1-Z, 2-Z, 4-Z-A, 5-Z-A, 7-A, and 8-A should be tested using a 12.5-mm- (0.5-in.-) diam mandrel. Systems 3-Z and 6-Z-A should be tested using a 15.6-mm- (0.625-in.-) diam mandrel. Pneumatic and manual mechanical bend test apparatuses may be used to bend the test panels.

d. Examine bend test panels. Test panels should be examined visually without magnification. The bend test is acceptable if the coating shows no cracks or exhibits only minor cracking with no lifting of the coating from the substrate. If the coating cracks and lifts from the substrate, the results of the bend test are unacceptable. Thermal spray coatings should not be applied if the bend test fails, and corrective measures must be taken. Figure 9-2 depicts representative bend test results.

9-13. Measuring the Coating Thickness

The thickness of the thermal spray coating should be evaluated for compliance with the specification. Magnetic film thickness gauges such as those used to measure paint film thickness should be used. Gauges should always be calibrated prior to use. Thickness readings should be made either in a straight line with individual readings taken at 2.5-cm (1-in.) intervals or spaced randomly within a 25-cm^2 (4-in^2) area. Line measurements should be used for large flat areas and area measurements should be used on complex surface geometries and surface transitions such as corners. The average of five readings comprises one thickness measurement. A given number of measurements per unit area (e.g., 5 per 9 m^2 (100 ft^2)) should be specified in the contract documents. Areas of deficient coating thickness should be corrected before sealing begins.

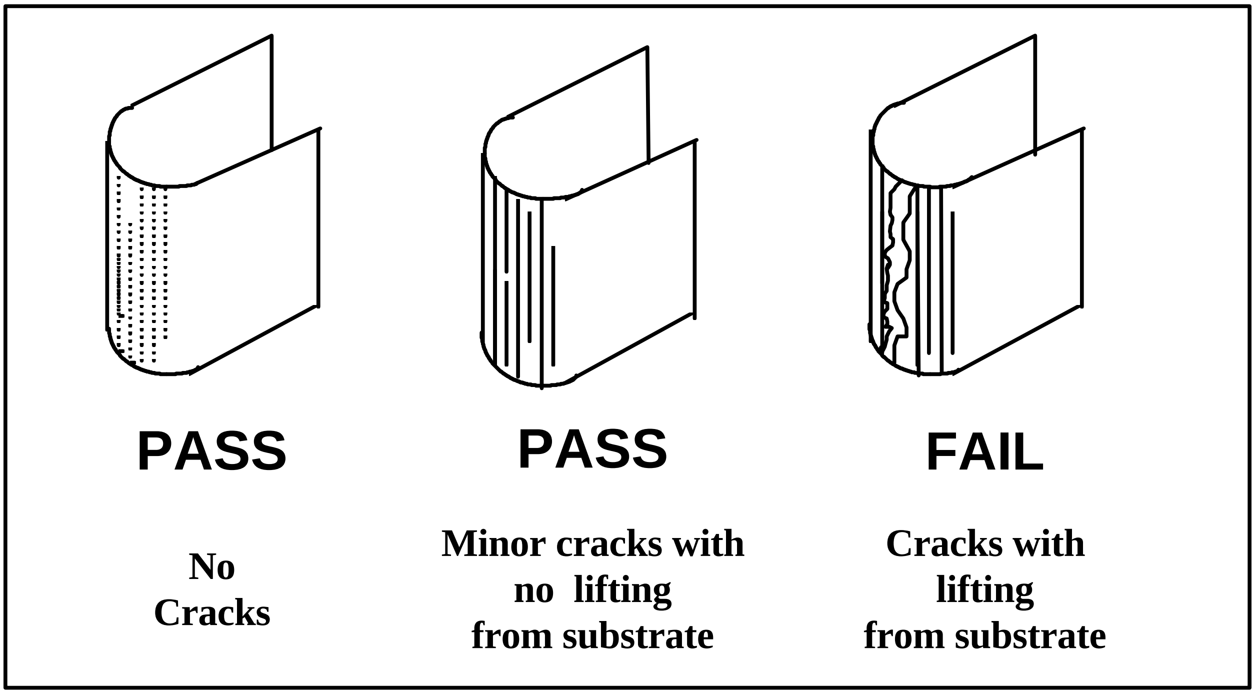

Figure 9-2. Representative pass and fail conditions for qualitative bend test

9-14. Inspecting the Appearance of the Applied Coating

The appearance of the applied thermal spray coating should be inspected for obvious defects related to poor thermal spray applicator technique or equipment problems. The coating should be inspected for the presence of blisters, cracks, chips or loosely adhering particles, oil, pits exposing the substrate, and nodules. A very rough coating may signal that the coating was not applied with the gun perpendicular to the surface or with too high a standoff distance. Coatings that appear oxidized or powdery should be evaluated by light scraping. If scraping fails to produce a silvery metallic appearance, the coating is defective.

9-15. Adhesion Testing for Quality Control

The adhesion of the thermal spray coating should be evaluated for compliance with the specification in accordance with ASTM D 4541. A self-aligning-type IV tester, described in Annex A4 of ASTM D 4541, should be used. A total of three adhesion tests should be performed in a 100-cm^2 (16-in^2) area, and the average of the three tests should be reported as a single measurement. The number of measurements per unit area (e.g., 1 per 45 m^2 (500 ft^2)) should be specified in the contract documents. Areas of deficient adhesion should be abrasive blasted, and the coating should be reapplied. Additional testing will probably be necessary to determine the extent of the area with poor adhesion. Adhesion testing should be minimized because the test method destroys the coating. Areas damaged by adhesion testing must be repaired by abrasive blasting and reapplication of the metallic coating. Adhesion testing is performed in a small area (100 cm^2 (16 in^2)) to limit the area that must be repaired. As an alternative to testing the adhesion to the failure point, the tests can be interrupted when the minimum specified adhesion value is achieved. This method precludes the need to repair coatings damaged by the test. The adherent pull stubs can then be removed by heating to soften the glue or by firmly striking the side of the stub. Table 9-1

Table 9-1
Typical Adhesion of Field- and Shop-Applied Thermal Spray Coatings Measured by Pull-Off Testing

Thermal Spray Material	Adhesion, kPa (psi)
Zinc	5100 (750)
Aluminum	10,880 (1600)
85-15 Zinc-aluminum	6800 (1000)

lists the recommended adhesion requirements for field- or shop-applied thermal spray coatings of zinc, aluminum, and 85-15 zinc-aluminum.

9-16. Inspecting the Sealer Coating

The dry film thickness of the sealer and paint coats should be evaluated for compliance with the specification in accordance with ASTM D 4138 “Test Methods for Measurement of Dry Film Thickness of Protective Coating Systems by Destructive Means.” Test Method A should be used. This method uses a tungsten carbide-tipped instrument to scribe through the sealer and paint leaving a v-shaped cut. A heavy dark colored marking pen is first used to mark the coated surface. The scribing instrument is then drawn across the mark. This process sharply delineates the edges of the scribe. A reticle equipped microscope is used to read the film thickness. A total of three thickness readings should be performed in a 100-cm^2 (16-in.^{2}) area, with the average of the three tests reported as a single measurement. The number of measurements per unit area (e.g., 1 per 45 m^2 (500 ft^2)) should be specified in the contract documents. Areas of deficient thickness should be noted and corrected, if practicable, by adding sealer or paint. Additional testing may be necessary to determine the extent of the area with deficient sealer or paint thickness. Thickness testing should be minimized because the test method destroys the sealer and paint. Areas damaged by adhesion testing must be repaired by touchup with sealer or paint using a brush or spray gun. Thickness testing is performed in a small area (100 cm^2 (16 in.^{2})) to limit the area that must be repaired. The sealer thickness should be checked prior to the application of paint coats, if practical, and the measurement procedure should be repeated for the sealer and paint.

9-17. Frequency of Inspection

The required frequency of inspection procedures should be spelled out in the specification. Inspection can be expensive, and care should be taken not to overspecify inspection procedures. Conversely, inspection has an inherent value that is sometimes intangible. It is difficult to measure the value added by inspection resulting from the conscientious performance of the contract. Thermal spray can be quite sensitive to the quality of surface preparation, thermal spray equipment setup, and application technique. Therefore, it is important to specify an appropriate level of inspection. Table 9-2 presents recommended frequencies for various inspection procedures.

Table 9-2
Recommended Inspection Frequencies for Selected Procedures

Inspection Procedure	Recommended Frequency per Unit Area
Surface profile	3 per 45 m^2 (500 ft^2)
Thermal spray coating thickness	5 per 9 m^2 (100 ft^2)
Thermal spray adhesion	1 per 45 m^2 (500 ft^2)
Sealer thickness	1 per 45 m^2 (500 ft^2)
Paint thickness	1 per 45 m^2 (500 ft^2)
Soluble salts	1 per 90 m^2 (1000 ft^2)

9-18. Documentation

The documentation of inspection activities provides a permanent record of the thermal spray job. Thorough documentation provides a written record of the job in the event of a contract dispute or litigation. Inspection records may also be used to help diagnose a premature coating failure. Future maintenance activities may be simplified by the existence of complete inspection records. As a minimum, at least one full-time inspector should be used on all thermal spray jobs to ensure adequate inspection and documentation. Inspection should be performed by a USACE inspector or a qualified third party inspector from a reputable firm. As a minimum, the inspector should perform and document the inspection procedures described in this chapter. Sample documentation forms for industrial coating activities are widely available through various sources.